ENGINEERING CASE LIBRARY

ECL 207A

AN ENCOUNTER WITH DEEP FREEZE (A)

This case describes the circumstances of an apparent engineering failure, and the investigations leading up to a likely explanation for the occurrence. The case is in three parts: Part A, general background; Part B, the detail viewing of objects; and Part C, interpretations.

NOTE: Names of firms, places, persons and products have been disguised.

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BACKGROUND

In early January, a newspaper report appeared in the Edmonton Chronicle. It stated that a fortunate father had saved his three children from certain death by a heroic walk through a blizzard.

The father had taken his children for a winter drive into a remote forestry reserve area. He was caught in a blizzard in weather of -30°F, and his vehicle became lodged in a snow drift. All attempts to free the vehicle were in vain. When finally his fuel supply ran out, he decided to walk toward the nearest available assistance. The children were left huddled in blankets behind the vehicle.

He remembered that he had passed a hut about 8 miles before and estimated that the next habitation would be closer. In fact he walked more than 18 miles before reaching safety. At the prevailing temperatures, with winds up to 10 m.p.h. and only barely adequate clothing, this was a noteworthy feat of endurance. A helicopter was dispatched as soon as possible and found the children alive, but suffering from severe exposure and frostbite. So much for the newspaper account.

A few days later, the vehicle was recovered by tow truck, and given an inspection by a licensed mechanic in the township. The father (Mr. Meyer) consulted a lawyer about legal proceedings against the manufacturer or the importing dealer for negligence in design or servicing.

The remainder of this case has been written in the form of a consulting report, and is based on information kindly supplied by the consulting engineer, Mr. W. O. Higgins. The report is in three sections, which permits discussion of various aspects of the case.

REPORT

INVESTIGATION OF FAULTY RUNNING CONDITIONS IN A FARINA FOUR-WHEEL DRIVE VEHICLE

Performed at the request of Mr. R. A. Meyer

INTRODUCTION

In late January, Mr. Meyer contacted the Department of Automotive Engineering with a request for advice concerning an incident which had occurred a short time before that date. Dr. F. Furrows, head of the department, asked the author of this report to take part in a first consultation on the incident. The vehicle concerned was viewed at the residence of Dr. Furrows on the evening of Wednesday, January 31st, 1973, with Dr. Furrows, Mr. Meyer, and the author present. At Mr. Meyer's subsequent request, a further investigation was undertaken at Dr. Furrows' residence, with Mr. Craig, licensed mechanic, and the author present. This work was performed on Monday, February 12th, re-assembly being performed by Mr. Craig on Tuesday, February 13th.

In the following descriptions, the terms "left" and "right" refer to sides as observed from the front, looking at the vehicle (i.e., opposite to the conventional side designation whilst driving). The vehicle is a Farina four-wheel drive hard-top, model XL50, equipped with a six cylinder in-line overhead valve engine. The gasoline tank is mounted underneath the passenger seat, with filler entering from the outside of the vehicle behind the door.

INFORMATION PROVIDED BY MR. MEYER

At the time of the incident, the vehicle had been in service for about 8000 miles, with regular servicing as stated in the operating manual.

It had apparently not suffered from loss of coolant (anti-freeze) during that time.

The incident occurred in the forestry reserve, north-west of Edmonton, Alberta, on a day with air temperature below -30°F. Drifting powder snow was present.

Powder snow had drifted into the engine compartment, filling the left side (where the starter motor and the ignition coil are located) to a depth of about 10 inches; this deposit had partially melted and refrozen to a fairly hard mass which surrounded the engine block closely. No mention was made of the condition of the engine compartment to the right (manifold and air-filter side) of the engine. The incident under discussion consisted of inability to move the vehicle effectively, poor running of the engine, high fuel consumption, lack of interior heat, but no indication of engine overheating.

Mr. Meyer checked the engine, and found the intake/exhaust manifold loose. He was able to turn the retaining nuts by hand. The manifold gasket was noticeably clean. The engine could only be kept running at fairly high speeds. After using all the gasoline in the regular fuel tank, Mr. Meyer filled 5 gallons from his reserve supply into the tank, and this quantity was used up within one hour. During his check, Mr. Meyer detected an unusual exhaust noise, louder and with deeper pitch. He also observed vapours of blue and white colours, the blue vapour being emitted upwards, the white vapour drifting downward. The location of origin of these vapours was at the centre of the manifold, between the carburetor and the cylinder head, through the gasketed joint at the central intake manifold (leading to cylinders 3 and 4).

After its retrieval by the nearest service station, the vehicle was inspected by a mechanic, and found to be in reasonable running order. About 2 quarts of coolant (anti-freeze) were missing. The engine showed a stain below the manifolds caused by some escaped fluid.

Since the incident, up to the time of the present investigation, the vehicle had been driven about 800 miles.

Mr. Meyer offered as his explanation the following statement: As the engine was being cooled to below -30°F at its base by the snow packed around it, the cylinder block contracted and permitted anti-freeze to enter the cylinders. This was then exhausted through the gasket gap, and stained the engine below the manifold.

PRELIMINARY VIEWING

Mr. Meyer was invited to bring his vehicle into the garage attached to Dr. Furrows' residence. After receiving the above explanations, Dr. Furrows and the author carefully looked over the engine compartment, with only minor disturbance of the equipment.

Among the features noted, the items relevant to this investigation were:

1) deposits of a gummy nature at the joint between cylinder head and cylinder block on the left side above the covers for access to the tappets and push rods; these deposits are unexplained, but could stem from bond material for the cylinder head gasket.

2) the inside of the distributor head was clean and unmarked; the cam movement available for automatic (centrifugal) spark advance was free and smooth.

3) the air filter intake points forward, and is situated about the top right corner of the upper radiator header; the intake air would receive little heat in this position, even if the radiator reaches full operating temperature.

4) the air filter housing is attached to the cylinder head by a bracket of about 4 inch length, held down by two of the cylinder head bolts, and bolted to the air filter case.

After a consultation between the author and Dr. Furrows, the advice given to Mr. Meyer was that further work was unlikely to reveal anything of value with respect to his opinions about the cause of the incident. Anti-freeze in the motor oil would no longer be detectable, traces of coolant transfer across the cylinder head gasket would not be easily visible, and other evidence of entry such as cracks could not definitely be made responsible for the incident due to the distance of about 800 miles travelled since the retrieval of the vehicle.

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SECOND VIEWING AND MECHANICAL WORK

At the request of Mr. Meyer, the vehicle was made available for further investigation. It was placed outside the residence of Dr. Furrows on the evening of Sunday, February 11th. During the night, the temperature reduced to sub-zero ranges.

On the evening of Monday, February 12th, attempts to start the vehicle with its own battery and with booster cables proved futile. Even removal of the air filter and injection of the gasoline into the top of the carburetor failed to permit starting of the engine. A service truck was finally able to bring the engine to life by push starting with Mr. Meyer at the controls. When the vehicle entered the garage at Dr. Furrows' residence, the engine had reached a reasonable running temperature.

On initial inspection it was found that (a) the oil level in the crank case was about 1/4 inch below the permitted "low oil level" mark on the dip stick, (b) the coolant (anti-freeze) level had dropped by about 1/2 inch since the last inspection. Because Mr. Meyer was about to take the vehicle for its regular servicing, no significance was attached to the low oil level. The lowering of the coolant level by about 1/2 inch (about 25 cubic inches of volume, nearly 1/2 pint) was considered noteworthy, especially in view of the elapsed time of 12 days. This represents about one quarter of the loss reported by Mr. Meyer in connection with the incident.

The inside of the air filter housing was marked by thin dust deposits in the form of droplets, ranging from the top to about 1/2 of the housing depth. Further dust edge marks were seen close to the bottom of the housing, as a continuous line reaching around 1/4 of the circumference towards the rear of the housing. A drain hole of about 0.1 inch diameter exists at the front of this housing.

The intake/exhaust manifold was removed. In the intake channels, a thin deposit of soot was visible, which was of fine and even texture and easily removable by wiping. Similar deposits were also found in the intake channels of the cylinder head. Noticeable mis-match existed between the intake and exhaust channels of the three items concerned (cylinder head, gasket and manifold). The manifold was

manufactured in two sections, one containing the intake channels, the other containing the exhaust sections. These items were bolted together below the carburetor mounting. The resulting matching face towards the cylinder head was not flat: differences of level of up to 0.010 inches were found. With proper tightening of the manifold nuts, such differences would still permit an adequate seal to be attained with the gasket provided. Better alignment of these sections of manifold could improve the seal somewhat.

An attempt to remove the two cylinder head bolts close to the central intake channel (cylinders 3 and 4) failed, even when using a hammer to strike the 19 mm open-end wrench. These bolts were obviously well tightened, and would retain that tension and the cylinder head gasket seal adequately.

The intake and exhaust valves were inspected through the opened channels of the cylinder head. The exhaust valves showed no unusual traces. The intake valves showed a thin smear of oil on the stems in the region of the valve quides (i.e., a usual occurrence, even for a new engine), and a soot deposit on the large-radius fillet to the valve head.

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CALCULATIONS

Based on the information at hand, and with some additional assumptions, calculations were performed to give greater insight into the problem.

Mr. Meyer's claim that cooling of the crank case could cause separation at the cylinder head gasket led to the first set of calculations. The coefficient of thermal expansion of cast iron (the usual crank case and cylinder head material) is given as $18.9 \times 10^{-6}/°F$. Assuming a cylinder head temperature of 200°F as adequately cooled, the maximum difference to the bottom of the crank case could be 170°F. Over the length of the engine of about 24 inches, this could give rise to a differential expansion of 0.077 inches. Over the approximately 3 inches of height of the cylinder head, the expansion difference could be 0.0096 inches. Such a large temperature difference could not possibly exist, because (a) the motor oil in the crank case would maintain a temperature of about 50°F even under the extreme cold conditions of the day of the incident. This would melt a gap of about one sixteenth of an inch between the crank case and the packed powder snow. Between the cylinder head and the crank case, the maximum temperature difference may reach 100°F, if the coolant level were below the gasket interface. Under such conditions the internal passenger compartment heater would no longer function. The differential expansions possible then (assuming that free expansion were possible) would be 0.045 inches over the engine length, and 0.0056 inches over the cylinder head height. As the bolts appeared to be adequately tightened, these thermal expansions would be taken up by elastic extension and compression of the engine parts. The release of sealing pressure on the cylinder head gasket would at best permit blow-by of combustion products into the coolant space (which may account for some evaporation of coolant), but would not allow coolant to be sucked into the cylinder space.

Considering the statement that the engine would only run at high speed, a speed of about 3000 r.p.m. may be assumed. This is equivalent to 90,000 firing strokes in one hour. If 2 quarts of coolant had been dissipated during that one hour, the volume would have been 0.0015 cubic inch per firing stroke. The actual volume would have been at most one-half of this figure, as the loss of coolant was taking place over a longer period of time.

Based on the statement of poor running, and loose manifold fixing, and bluish vapour emitted, if we assume the blue vapour to be unburned gasoline, and only 1/2 of the consumed gasoline to be burned, the following results were obtained:

1) volume of unburned gasoline emitted from the manifold joint would be 0.0077 cubic inches per firing stroke, a factor of ten over the possible coolant volume, and therefore probably more easily seen.

2) with 2-1/2 gallons of gasoline burned in one hour, the equivalent consumption for normal running would be 16 miles per gallon at 40 miles per hour, 20 m.p.g. at 50 m.p.h., or 24 m.p.g. at 60 m.p.h.; these values are within the expected consumption range for this engine, under normal working conditions.

CONCLUSIONS

The explanation offered by Mr. Meyer can be discounted on the grounds that (a) the relative expansions which could be possible would be too small to affect the transfer of coolant into the combustion space, and (b) there is no other obvious connection between the cooling channels and the cylinder/manifold system.

A very likely explanation of the incident may be found from the fact of drifting snow. Air is being sucked into the air filter, and as its intake points forward with little air heating in the process, it is very likely that the air filter housing became progressively filled with powder snow (in a similar manner to the snow packing in the engine compartment). Melting of this snow would be very slow, due to the small heat transfer path of the filter mounting bracket, and insufficiency of radiant heat.

An air filter blocked by snow would provide an appreciable resistance to air flow, and consequently a high vacuum in the intake channels. This would tend to suck an appreciably increased quantity of gasoline from the carburetor. In this choked condition, the engine could only be kept running at high speeds, and would suffer from an apparent loss of compression. The speed of combustion of the resulting rich misture is much slower than for a normal mixture, such that combustion would continue in the exhaust pipe; probably only 1/2 of the burned fuel provided usable power. This after-burning in turn provides a high back-pressure into the cylinder, which in an extreme condition can blow back into the intake channels. As

the flame had probably died at that point, little or no combustion would take place in the intake. The back-pressure would only exist during the period of valve overlap, about 50° of crank angle when both valves of one cylinder are open.

Under the circumstances of a loose manifold and leaking joint, the back-pressure in the intake could force the contents of the manifold to exit from the intake duct region into the engine compartment. This would appear as a mixture of air, water vapour from burned fuel, soot (carbon) from burned fuel, and unburned fuel. Soot would preferentially be deposited on the walls of the intake channels. Its particles are heavier, and would therefore not be pushed through the gasket gap as easily. Water vapour would condense quickly in sub-zero temperatures, and would tend to sink towards the floor. Unburned gasoline would also condense, but as it is lighter, it would tend to continue rising. During the induction stroke, sufficient air could be drawn through the gasket gap to permit continued running of the engine, but only at high speed.

At the prevailing temperatures of below -30° F, the sense of smell is almost absent, and detectable vapours are too diluted. It is therefore plausible, that Mr. Meyer would mistake gasoline "without smell" for anti-freeze. The stain on the side of the engine is most probably motor oil, leaking in small amounts from the valve guides and issuing through the faulty gasket joint onto the crank case. As this strain is mostly rearward of the carburetor, it could have been blown into this region by the normal driving air stream, or it could have leaked preferentially in this area by slightly looser fits of valves in their guides. As gasoline is a good solvent for oils and other products, the clean appearance of the manifold gasket also fits the explanation proposed here.

In the author's considered opinion, the incident to which Mr. Meyer was subjected was most probably due to the effects of drifting powder snow, which caused a blockage of the air filter. Proof positive of this could only have been obtained by inspection before the vehicle was brought into a location of higher temperature.

signed W. O. Higgins, P. Eng.
February 27, 1973

POSTSCRIPT

Mr. Meyer contacted the consulting engineer, Mr. Higgins, by telephone after receiving the report. He sounded extremely disappointed about the results, but was satisfied that the given explanation was reasonable. He also asked for some advice about modifications to the engine compartment which could help to avoid a recurrence of this fault.